

Smoothing the Way to Print the Next Generation of Computer Chips

A frantic race is under way in the microelectronics industry to integrate more and more capability onto computer chips. Yet conventional optical lithography—the current practice of directing light through a mask, or reticle, to print integrated circuits on chips—is being pushed to its limits. When beams of light cannot be made thinner, the number of circuits that can be written on a given chip can go no higher. Extreme ultraviolet lithography (EUVL), which has emerged as the lithographic method of the future, is expected to be capable of reducing the feature size from 130 nanometers to less than 50 nanometers.

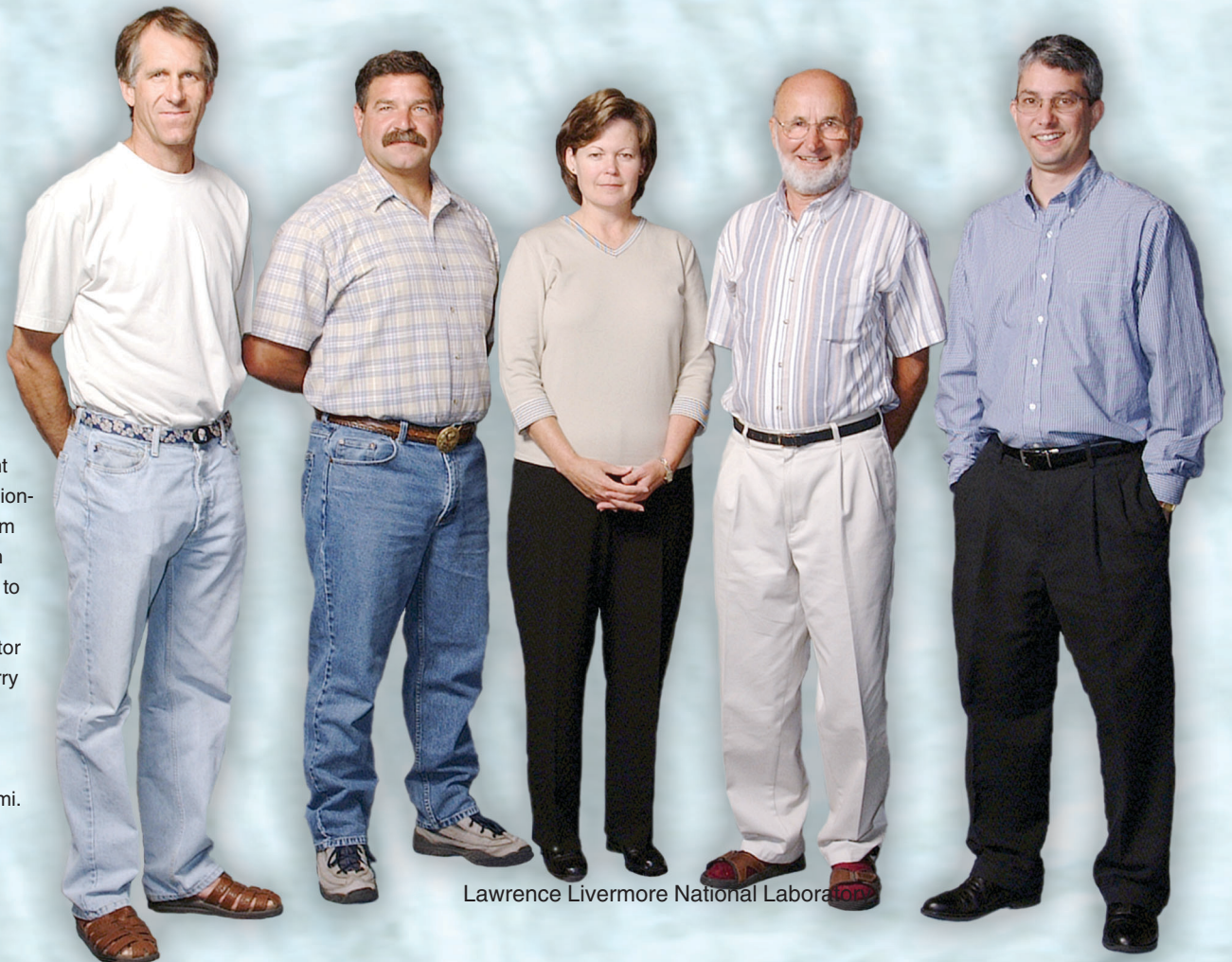
“One of the highest risk areas for EUVL technology was the development of the reflective reticle,” says materials scientist Paul Mirkarimi. Mirkarimi’s team has not only overcome that concern but also won an R&D 100 Award for the ion-beam thin-film planarization process, which generates nearly perfect surfaces for reticles and other critical components for EUVL. With this novel deposition and etching process, surfaces that

have been contaminated with particles piled up to 70 nanometers high can be made almost perfectly smooth. The resulting profile of the thin-film coating is less than 1 nanometer high. Imagine “smoothing” a 70-story skyscraper to the height of a single-story house.

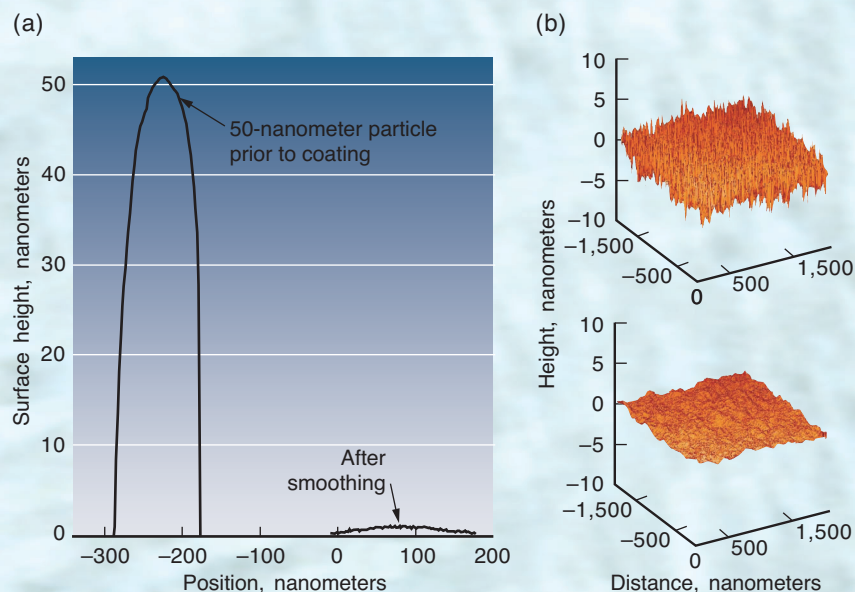
Almost Perfect Surfaces

An EUVL reticle blank consists of a substrate coated with a molybdenum–silicon (Mo/Si) multilayer film designed to have optimal reflectivity at extreme ultraviolet (EUV) wavelengths of 13 to 14 nanometers. Reflectivity is critical because EUVL uses strongly attenuated EUV light directed at reflective optical components to create minute features. The film is coated with a buffer layer and an absorber layer and is processed with an electron-beam lithographic tool to form a patterned EUVL reticle. The finished reticle absorbs EUV light at specific locations and reflects it everywhere else.

Development team for the ion-beam thin-film planarization process (left to right): Dan Stearns, Victor Sperry, Sherry Baker, Eberhard Spiller, and Paul Mirkarimi.



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Ion-beam thin-film planarization can be used to fabricate nearly defect-free reticles and projection optics for extreme ultraviolet lithography.

(a) With the deposition and etching process, a 50-nanometer particle is smoothed until it is less than 1 nanometer high, or about the height of a single atom. (b) Overall surface roughness is dramatically reduced as well.

The key challenge in developing this reticle technology is to manufacture reticle blanks that are virtually defect-free. The allowable defect density is about 0.0025 defects per square centimeter for defects of approximately 50 nanometers and larger. This density corresponds to just one defect for every two 15-centimeter-square reticle blanks—or a single defect the size of a basketball on a flat surface slightly larger than the states of Oklahoma and Texas combined. Says Mirkarimi, “To our knowledge, these are the most stringent defect specifications ever required for a coating process.”

The Livermore team’s technology smooths, or “planarizes,” substrate particles during the multilayer coating process. A primary ion source sputters material off a target onto the substrate, and a second ion beam etches, assisting in the formation of a smooth, uniform film with remaining defects less than 1 nanometer high. Defects that small—just a few atomic layers thick—are considered to be benign according to EUVL printability modeling.

Two other deposition processes—magnetron sputtering and ion-assisted electron-beam evaporation—can also be used to print computer chips. But magnetron sputter deposition results in larger substrate particles. And at least for Mo/Si coatings, there are no data to suggest that ion-assisted electron-beam evaporation smooths out defects.

Mirkarimi’s team also demonstrated that their planarization process smooths rough substrates, making it applicable to projection optics, another critical EUVL component. The figure and finish specifications of these optics are about 0.1 nanometer, which are extremely challenging and expensive to achieve simultaneously. “There is the risk that sufficient quantities of these optics won’t be produced because of the difficulty in fabricating them,” says Mirkarimi.

With the planarization process, coatings with EUV reflectivities of about 67 percent can be obtained on substrates

with roughness of approximately 0.4 nanometer, which is sufficient for projection optics. Thus, finish specification for the optics could be relaxed, significantly reducing the production costs and increasing the availability of these optics. Livermore’s process is equally effective for smoothing homogeneous films. By successively depositing and etching thin silicon layers, the team achieved a level of particle smoothing with homogeneous silicon films similar to the level accomplished with Mo/Si multilayer films.

Putting EUVL to Use

With the smaller feature size that’s possible with EUVL, many more transistors can be placed on an integrated circuit. Desktop computer microprocessor chips will operate at more than 10 gigahertz, and random access memory chips can have gigabyte capacities. Such powerful, affordable computers are expected to make a variety of computationally intensive applications practical. Real-time, multilanguage voice recognition and translation are just two examples.

In 2001, the Semiconductor Industry Association reported that the industry was annually manufacturing about 60 million transistors for every man, woman, and child on earth. By 2010, this number is expected to be 1 billion transistors, as integrated circuits make their way into even more devices used in our daily lives. If we think our lives are computerized now, we obviously haven’t seen anything yet.

—Katie Walter

Key Words: extreme ultraviolet lithography (EUVL), ion-beam thin-film planarization, R&D 100 Award, reticle.

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